THE LIFE AND WORK OF DAVID HUGHES.

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When I received an invitation from the Council to give some account of the life and work of David Hughes, on the occasion of the centenary of his birth, my thoughts naturally turned to the men of the past who rank as discoverers. How seldom we think of them! We hardly ever get a chance to remember them, because we are so busy all day making use of their discoveries. Fortunately for us, that makes no difference to the discoverer. He lives in a world of his own, happy in the absorbing interest of his work. He is content to do the ploughing and the sowing, even though he may never see the harvest.

Hughes was a discoverer in the broad sense. He spent the best part of his life in creative work from which we benefit, and we are met here to do honour to his memory. In the time available I can only give a brief account of his work. Much that he did I must pass over unnoticed, or with only a bare reference. To understand the touch of genius in Hughes it will, however, be enough to look at the two outstanding achievements of his life; first the invention, in his early years, of the synchronous type-printing telegraph, and secondly, in later life, the discovery of the microphone. In these his genius was at its height, and (to use an engineering metaphor) it is the " peak values " that count when we attempt to estimate genius.

David Edward Hughes was born in London on the 16th May, 1831. His parents were Welsh. His grandfather was a bootmaker, first at Bala, in North Wales, and afterwards in London. When David was 7 years old his father emigrated to America, taking his family with him. They settled in Virginia, and there the boy was brought up and educated. Being of Welsh descent Hughes was naturally musical, and when we first hear of his doings he has arrived at the age of 19 and been appointed Professor of Music in St. Joseph's College, Bardstown, Kentucky. At this period he was already showing a keen interest in science, and by the time he was 20 he was giving lectures in the College on natural philosophy. Although for the time being a professor, a title he retained to the end of his days, he was not destined to spend his life in teaching. There was other work for him to do. He was thinking of electricity and its application to telegraphy, and no doubt learning, as best he could what there was to be known about it.

In the middle of the last century electric telegraphy was undergoing rapid development. In England we were using Wheatstone's needle instruments. In America Morse had produced his ink writer—the first telegraph instrument to print messages in dots and dashes on a ribbon of paper. He had also devised an excellent alphabetic code for the dots and dashes, an invention for which the whole world is indebted to him. Notwithstanding the existence of the Morse Code, efforts were being made to dispense with alphabetic codes by making the telegraph instrument print the messages in plain type for anyone to read. Wheatstone exhibited an instrument of this kind in London in 1841, this being worked on the step-by-step principle, I believe. In America, House and others had brought printing telegraphs into use. All these embodied some form of step-by-step mechanism, a method of working which has the grave disadvantage that it needs, on an average, about 12 impulses of current to print a single letter. On a short line with little capacitance this does not matter very much, but on long lines with much capacitance the separate impulses tend to coalesce into a long-drawn-out current which fails to drive the typewheel forward by the required number of steps.

At the age of 21, and possibly a little earlier, we find Hughes, in his spare time, inventing a printing telegraph of his own and putting into it features of great ingenuity. In 1854 he resigned his teaching appointments to devote himself to his invention, and a year later he had a trial instrument working successfully. Hughes departed entirely from the step-by-step principle. In place of it he devised a method of synchronous working between a revolving arm at the sending end of the line and a revolving typewheel at the receiving end. In his first model, which remained in use for some 20 years, the revolving arm was part of the electric circuit. It was connected to the line and rotated round a ring of contact studs, a stud for each letter of the alphabet and one or two signs. Any stud could be connected to the battery by its corresponding key, the keys being arranged side by side on a keyboard.

At the receiving end the message was printed on a paper ribbon by the action of an electromagnet in circuit with the line. Each time the contact arm at the sending end passed over a live stud, a current traversed the line and the electromagnet; thereupon the armature of the magnet forced the paper ribbon into momentary contact with the typewheel, and a letter was printed. The revolving arm and the typewheel being " co-phasedly synchronized " (to use Lord Kelvin's phrase), the letter printed at the far end of the line corresponded to the key which the operator was holding down at the sending end. It will be noticed that only one impulse of current was needed to print a letter.

About the year 1876 Hughes substituted mechanical detents for the ring of contact studs, and in place of the many contacts he provided a single butt-contact switch-arm for connecting the battery to the line. The detents were attached to the operating keys in such a way that the depressing of a key raised the corresponding detent into a position in which it came into

engagement with the revolving arm, which was now solely a mechanical device and served to operate the switch key every time it came into engagement with a detent. The operating keyboard remained unchanged, and Hughes, being familiar with musical instruments, thought he could not do better than employ the keys of a pianoforte, arranging the black and white keys alternately on the keyboard.

Inventions which come from outside an industry often display originality of thought, and that was true of the Hughes printer. It contained features of striking originality, but it was more than original. The Hughes printing telegraph, like all great inventions, was a complete and practical adaptation of means to end. It worked, and it worked well. It deserved to succeed, and it did succeed. The Hughes printer was so good that in 1856 it was adopted by the American Telegraph Co. In 1857 Hughes came over here to see what could be done with his invention in England, the home of Wheatstone. He was soon to discover one of the most deep-rooted instincts of the Englishman. Show him a new machine of any kind and he looks at it half shyly. Ask him to adopt it, and his instinct tells him to say "no." He vaguely imagines difficulties, and it saves so much trouble to say "no" at once and have done with it. He said "no" to Hughes.

Having discovered that he was not recognized as a prophet in the home of his birth, Hughes went over to Paris and showed his invention to the officials of the French Government Telegraph Service. They liked the look of it, and very soon the Hughes printer was installed on some of the more important telegraph lines in France. Its use extended and within a few years had spread all over the country. Hughes next went to Italy, where he met with the same success. Russia, Turkey, Holland and other countries followed suit, and in a few more years the Hughes type-printing telegraph was at work all over Europe, the advantage of receiving telegraph messages in print being fully appreciated on the Continent as well as in America.

And now we realized that we were going to be troubled over Hughes after all. A submarine cable had been laid across the Channel and telegraph lines were available from London to the Continent. It must have been disconcerting to us to discover that for intelligent communication with the foreigner it was essential, not only to speak in the same language, but also to use identical telegraph instruments at the two ends of the line. It must also have been annoying, having said "no" to Hughes, for us to learn that the telegraph authorities on the other side of the Channel were determined to use the Hughes printer at their end of the line, no matter what we might do. Compromise, the Englishman's way out of all difficulties, was clearly impossible, and Hughes instruments were therefore installed at the London end of the Continental lines—not on account of their merit, but solely as a concession to foreign idiosyncrasies. The adoption of the Hughes invention in England went no further; almost alone among civilized countries we continued the practice of transmitting telegraphic messages in code and then writing them out by hand.

It is one thing to make a successful invention, but quite another to get paid for it. Too often the inventor is left to pick up the crumbs from the rich man's table. Hughes, however, saw to it that he was well paid for his work and when he returned to England in 1875, from which time London became his home, he was well on the way towards making a large fortune out of his printing telegraph. He now entered upon the second period of his life, and at the age of 44, with ample means, he found leisure for the work he loved best—experimental research. The opportunity for making a discovery was to come almost immediately.

In 1876 Graham Bell showed his miraculous telephone at the Chicago Exhibition, and the world soon realized that the problem of the transmission and reproduction of articulate speech had been solved. Bell's telephone was, however, capable of serving another purpose. As an extremely sensitive detector of minute variations in the strength of electric currents it formed a novel and very valuable weapon of research. When the simple construction of Bell's telephone became known and experimenters found it an easy matter to make serviceable instruments for their own use, the way was open for the investigation of many obscure effects associated with current variation. Hughes was among the first to employ the new instrument for research, and with the aid of a couple of Bell telephones made with his own hands he was soon engaged in the lengthy series of experiments which ultimately led him to the discovery of the microphone. He must have set to work early in 1877, but no doubt much time was spent in preliminary and unrecorded experiments before Hughes found himself on the right path. Even then he had a long way to go, for as he himself remarks:—"however simple the microphone may appear at a first glance, it has taken me many months of unremitting labour and study to bring it to its present state." The work was all the more difficult because there was no previous knowledge to serve as a foundation. He was working in an entirely new field, with nothing but his mother-wit to guide him. Hughes was no theorist, and by what mental process he passed from one experiment to the next will never be known. Sir Oliver Lodge has suggested what sort of process it was, in the happy phrase "Hughes thought with his hands"; the truth is that he was born to make experiments and to find his way in the dark.

Hughes discovered that conductors in contact under slight pressure were sensitive to sound. Towards the end of 1877 he found himself in possession of the essential facts, and early the next year he prepared a paper describing the microphone in its various forms and recounting some of the steps that led to the discovery. This paper, on "The Action of Sonorous Vibrations in varying the force of an Electric Current," was read at a meeting of the Royal Society on the 8th May, 1878. In his paper Hughes tells us that, being aware of the effect of light upon the electrical resistance of selenium, he had an idea that sound might possibly have a similar effect upon electrical conductors. Starting from this point he tried in numerous experiments to discover the effect (if any) of sound upon conductors of various kinds and in different states, but without success. Next came experiments in which wires carrying electric

current were subjected to stresses of bending and stretching. These, too, all failed to show any effect of the kind for which Hughes was looking.

In the course of one of the stretching experiments, however, the wire broke and Hughes noticed that the rupture was accompanied by a peculiar sound in the telephone to which the wire was connected. Pressing the severed ends of the wire together gave rise to similar sounds in the telephone. Hughes now discovered that while the two ends of the broken wire were being lightly pressed together,sounds impinging upon the bad contact were accompanied by sounds in the telephone. In other words, primary sounds acting upon the bad contact were transmitted to the telephone and, as Hughes says, " reproduced very imperfectly." It is not stated what the primary sounds were in this case, but from the context it is clear that, from the beginning of the experiments, speech was one of the sounds employed. Although reproduction had, so far, been very imperfect, it was encouraging to reproduce sound at all, and Hughes must have been aware that he was now on the right track. He had discovered that the bad contact formed by two conductors touching each other under slight mechanical pressure is sensitive to sound waves.

A steady contact cannot be obtained by holding two wires together by hand, and in the next experiment which is described in the paper gravitational force is substituted for hand pressure. Hughes had some small French nails—rods of mild steel with a clean bright surface. Taking two of these, he laid them side by side on a little piece of board, with a space of perhaps $\frac{1}{2}$ in. between them, sticking them down on the board by means of sealing wax. The two nails were then electrically connected together through a battery and a telephone. To close the circuit Hughes laid a third nail across the other two, thus forming two bad contacts where the cross nail rested lightly upon the fixed nails, its weight providing the necessary pressure. A small nail does not weigh much, and, the pressure being very slight, the arrangement was extremely sensitive to pressure variations such as those of sound waves. Almost inaudible sounds gave rise to loud sounds in the telephone. Hughes still finds that the reproduction is very imperfect, however, and he goes on to describe how a much better result was obtained by building up what he aptly calls a "log hut" of nails. Even with this, to use his own words, "only the grosser sounds are reproduced." He is still hoping to reproduce speech, and the more favourable result obtained with the log hut of nails suggests that with a greater number of contacts he may succeed.

Hughes now buys some metallic powder, a mixture of zinc and tin which appears to have been used for some ornamental purpose. Returning to the simpler form of three nails, he inserts a little of the powder under the cross nail at the points where it rests upon the other two, and with this modification he at last finds what he is seeking. He tells us that, with this arrangement of three nails and a little metallic powder, "speech is clearly reproduced in the telephone." He has arrived at the great discovery—the multiple-contact microphone —and has proved it to be an effective means of transmitting articulate speech. The difficult part of the work was done, and, to quote Hughes again, " all that remained was to find the best material." He goes on to say that any metal would do for the powder, but most metals oxidize and this will lead to trouble. Platinum would be free from this defect, and carbon suggests itself as a cheap substitute. A trial was therefore made with carbon, and it was found to work very well. As a matter of fact carbon is so effective that three little sticks of porous willow charcoal, arranged like the three nails, will transmit speech quite well without the addition of any powder.

Although carbon proved to be quite satisfactory and in the end turned out to be the best material for the purpose, Hughes still had metallic granules in mind and at this point we can almost see him " thinking with his hands." Heating three small sticks of willow charcoal to a white heat, he plunged them into a bath of mercury. As the porous charcoal cooled down the mercury ran into every pore and when the sticks were taken out of the bath they were found to be fully charged with tiny drops of mercury. These three little rods of mercury-laden charcoal, arranged like the three nails, gave exceptionally good results—in fact the best Hughes had so far obtained. This I can confirm from my own experience. Immediately after the publication of his paper I repeated all the experiments he had described and found the mercury-cum-charcoal microphone to be far more sensitive and clearly articulate than any other form. I placed it in a room where conversation was going on, and on listening-in at the far end of my telephone line I heard the voices as clearly as though I had been in the room; I heard every word, although the occupants of the room did nothing to assist the experiment. And this, too, with nothing more than three tiny pieces of charcoal containing mercury; no diaphragm, no mouthpiece, no accessories of any kind—nothing but the ingenuity of Hughes. There was a rapid falling-off in the results, however, and in a couple of hours afterward this wonderful microphone was no longer capable of transmitting either speech or any other sounds.

Hughes remarks upon the sensitivity of the simplest form of microphone—the three rods, nails or carbon sticks. In this form, he says, " the microphone will do for faint sounds what the microscope does for human vision," and as an illustration he describes an odd experiment, which perhaps only Hughes would have thought of. He confined an ordinary house fly under a glass tumbler, along with a microphone made of three nails mounted upon an empty matchbox. With this primitive arrangement Hughes reports that he " could hear the fly walking with a peculiar tramp of his own." The foot of a fly being a minute sucker, when the foot is lifted in the act of walking the sucker is suddenly released with a little staccato pop. I repeated this experiment and heard a lively popping as the fly walked slowly along the matchbox; it was a strange sound to hear, and I knew what Hughes meant by a " peculiar tramp of his own." What are we to think of the imagination of a man who sets out with the aid of three small nails to hear a fly walking? Would any of us have thought of it?

To the simplest form of contact sensitive to sound, Hughes gave the name " microphone." He was impressed by the much greater power associated with a.

multiplicity of contacts, and in his paper he refers to forms of multi-contact microphone as " transmitters." We have long ceased to draw a distinction between the two types, and to-day any device in which sound varies the pressure on electrical contacts is called a microphone, whatever the number of contacts it contains.

As soon as Hughes had published his account of the microphone there followed the usual crop of fragmentary anticipations, to which the circumstances of the time were particularly favourable. Bell's telephone had naturally excited intense interest, and inventors almost immediately began the search for some more powerful form of transmitter than the Bell instrument proved to be. In this way it happened that while Hughes was patiently investigating the effects of sound upon electrical contacts, more than one ingenious inventor hit upon some isolated example of microphonic action and forthwith embodied his idea in a patent. When, however, we have awarded whatever credit truly attaches to a sporadic disclosure of uncorrelated facts, the honour must go to the man who begins at the beginning and perseveres to the end; the man who feels his way from experiment to experiment, gathering the facts as he goes, and who continues his efforts until the full scope of the inquiry has been brought to light. This was the way of Hughes, and when his experiments had disclosed the main body of facts relating to the action of sound upon electrical contacts he gave his knowledge freely to the world. In the true sense of the word, he " discovered " the microphone. For a time attempts continued to be made to embody various half-fledged ideas in microphonic transmitters, but they all disappeared in the course of a few years. Finally the principle on which Hughes lays stress in his Royal Society paper—multiplicity of contacts—was fully recognized by designers, and the granular microphone became the standard type.

Hughes had now done two great things: his printing telegraph was at work in nearly every civilized country, and he had given the microphone to the world. It was labour enough for any one man, first as inventor and then as discoverer. But the born experimenter cannot stop while there is breath in his body, and Hughes continued his research work, exploring new fields as best he could. His experimental notebooks for this later period have survived, having been presented to the British Museum by Mrs. Hughes after her husband's death. They make interesting but difficult reading, and from them we learn that early in 1879 Hughes was engaged upon experiments with his induction balance. This ingenious instrument excited much interest at the time and it was confidently, but rather rashly, anticipated that the balance would prove useful in a number of ways. But it was not to be. The possible utility of the Hughes balance was dependent upon eddy currents in the pieces of metal that were to be balanced against each other. Fifty years ago the phenomena of eddy currents were almost unknown, but in the light of present-day knowledge is it easy to see that the quantity measured by the balance was the product of at least three variables, and as there was no means of separating the factors the apparatus had a very limited field of utility as a measuring instrument.

At this time Hughes was led, by the accident of a bad contact in an induction balance, into experiments which were to make him acquainted with strange and bewildering phenomena. The result was a prolonged investigation which, for want of a key, brought no results. Having traced the effect of a bad contact to what was described, in the language of that day, as the " extra-current " (i.e. the transient current that flows in an inductive circuit on cutting off the primary current), Hughes made a few experiments to find his way and then constructed a secondary circuit for the purpose of detecting the effect of extra-currents at a distance from the primary coil. In his secondary circuit he included a telephone, and a novel device which he describes as his " thermopile." On breaking the circuit of an adjacent primary coil in which a current was flowing, the resultant brief current in the secondary circuit gave rise to audible sounds in the telephone. To us this seems only natural, but Hughes had a theory of his own to account for the current in the secondary circuit. He supposed that by some process of "conduction " (which he does not explain) the extra-current in the primary coil generated thermo-electric currents in the secondary circuit, and thus caused the sounds heard in the telephone. For Hughes this odd explanation was summed-up in the word " conduction," his thermopile and the hypothetic thermo-electric currents being, apparently, the means by which the mysterious conduction was made manifest. All this seemed rational enough to Hughes 50 years ago, but at this distance of time it is difficult, if not impossible, to follow the working of his mind.

What Hughes thought, however, is not so interesting to us as what he did. In one or two of his rough sketches of the secondary circuit there is something which looks like a conventional representation of a microphone, and from this and other evidence there can be no reasonable doubt that Hughes was making use of a microphone with metal contacts which had lapsed into the non-conducting state, and by so doing had become a coherer. In his notes he refers to his " thermopile " as " a new instrument of research," and if it contained an effective coherer it certainly was so. Whether the " thermopile " contained anything in addition to a coherer is not made clear, however, and another difficulty is the absence of the battery cell which should go with the coherer. It seems possible that in the early experiments the extreme sensitivity of the telephone was the reason for the observed effects, there being no coherer action. In the later stages there is little doubt that a feeble voltaic cell was introduced into the secondary circuit, in which case the sensitivity of the secondary circuit as a detector of the effect of extra-currents would be immensely increased.

The new instrument of research—telephone, thermopile, coherer, or whatever it was—proved to be marvellously sensitive to extra-current effects; and by listening with a telephone Hughes set to work to detect these effects at greater distances from the primary coil in which the extra-currents occurred. Having arranged a primary coil and a current interrupter in his experimental room, Hughes carried his secondary circuit about the house, listening with the telephone for signs of the extra-currents. There was no difficulty in detecting them

anywhere in the house, even when the secondary circuit was carried to a distance of 60 ft. from the primary coil, this being the greatest possible distance indoors. Out-of-doors Hughes carried the secondary circuit to much greater distances without finding any serious difficulty in detecting the extra-currents. Beyond 200 to 300 yards the sound emitted by the telephone became very faint, however, and at 500 yards Hughes found that he could not detect the effect of the extra-currents with any certainty. These were very great distances at which to detect inductive effects, and there can hardly be a doubt that they were made possible by the introduction of a voltaic cell into the secondary circuit, in addition to the coherer and the telephone. A thorough examination of the notebooks relating to this research would probably clear up the question of the use of a cell, and might possibly throw much-needed light upon the mysterious " thermopile."

In these experiments the breaking of the circuit of the primary coil was done under conditions which, as we now know, must have resulted in high-frequency oscillation. Hughes did not know this; he was not aware that his extra-current was oscillating and that the primary circuit was radiating energy in the form of electromagnetic waves. It is not easy, in the absence of special precautions, to break an inductive circuit without causing oscillation, and a host of experimentalists before Hughes must have been generating electromagnetic waves without knowing it; to say nothing of those who, for the past 200 years or more, have been discharging Leyden jars with violent sparks. There was, therefore, nothing novel in the fact that Hughes, unknown to himself, was employing a radiating primary circuit. But as it had a telephone, with or without a coherer, there was something entirely novel in his secondary circuit; and although mystery still attaches to what he calls his " thermopile " Hughes did, in fact, discover the coherer. This device was to be re-discovered many years later by Branly and others, and applied by them to wireless telegraphy.

All the early experimenters, Hughes among them, who without knowing it generated electromagnetic waves and in one or two instances detected them at a distance, were working at the fringe of a vast field for discovery—the wireless field. None of them knew of the gate into the field. And even after Clerk Maxwell, in his electromagnetic theory of light, had forged the key to the gate, a good many years went by before Hertz, who knew about Maxwell's theory, took the key, opened the gate and walked into the field to begin the work of exploration that led to wireless communication. Unfortunately Hughes was not in possession of the key. In his notebooks he attributes the strange phenomena he was observing to some sort of conduction, a misleading idea to which he clung with remarkable tenacity. For him it seemed to explain the facts. In the absence of Maxwell's key, however, no rational explanation was possible, and from first to last the extra-current effects remained a baffling mystery, not only to Hughes but also to the eminent scientific men to whom he showed his experiments. I have referred to this research in some detail because it gave rise to a good deal of misunderstanding, both at the time and long afterwards. When the experiments of Hertz had solved the mystery it was natural to look back at what Hughes had done and to see in his work much more than he himself was aware of at the time.

Hughes was elected a fellow of the Royal Society in 1880, and five years later he was awarded the Society's gold medal for his researches. He was a Member of our Institution, and in 1886 he filled the office of President His later years were occupied with research work, and by various activities in the scientific world. Then, after a short illness, the end came on the 22nd January, 1900. By his will he left substantial sums to scientific societies, both here and in France, the Hughes Scholarship of the Institution being among these bequests. The greater part of his large fortune was left to four London hospitals. From his earliest days Hughes had been accustomed to frugal living, and when his printing telegraph made him a rich man he showed no desire to change his way of life. What his large income was to him it is impossible to guess, and for us his riches present an odd contrast to the unassuming simplicity of his life. But such matters as these belong to the ephemeral part of him. Hughes survives in his two works of genius, and we are still reaping the harvest sown by his hands.

His printing telegraph is still employed on the Continent, and so long as it is retained there it will be found at work on the London end of the Continental lines. It is a surviving tribute to the genius of a man who, when just out of his teens and possessed of no more knowledge of electricity than he could pick up as he went along, invented the synchronous type-printing telegraph that was to spread all over the world and to become the source from which later inventors were to derive many of their ideas.

The Hughes telegraph is now rapidly dying out, being replaced after 80 years by instruments of much greater speed. But in the microphone Hughes survives in our everyday life, and the microphone is likely to survive because the Bell telephone needs it. As an electromagnetic machine the Bell telephone is reversible; it acts equally well either as a vibratory electric generator or as a vibratory motor. When used as a transmitter it is acting as a generator, but in that capacity it cannot possibly transmit (in the form of alternating current) a greater amount of energy than it receives as acoustic energy. In practice, the acoustic energy is that of the human voice, and, as Crandall and Mackenzie have shown, the total acoustic power of an average voice is only about 12 or 13 microwatts; an amount which is quite inadequate for more than very moderate distances. In a widespread telephone system it is necessary to transmit far more energy, and since the human voice cannot supply what is wanted the energy can only be obtained from some extraneous source such as a battery, the battery current being controlled by the acoustic waves. In short, it is necessary to supply energy by relay, and this is the function of the microphone.

A little explanation is necessary to show how a microphone acts as a relay. In such works of reference as I have consulted I have not found any clear explanation of the action of microphonic contacts, and I can only give my own account of the way in which a microphone works. It is simple enough, and is founded upon a fact

determined by experiment. When two conductors touch each other at a point, under slight mechanical pressure, the conductance of the contact is proportional to the pressure; this law holds good over a considerable range of pressure from zero upwards. Sound waves are waves of pressure, and if they impinge on one of the conductors, the other being rigidly fixed, they vary the contact pressure and thereby change the conductance of the contact. The conductance variations give rise to ripples in any current which traverses the contact, and since the variations are proportional to the pressure the ripples of current will be faithful images of the sound waves. They will not merely be of the same frequency, but they will also be of exactly the same shape as the sound waves, and consequently when the ripples pass through the receiving telephone the sounds emitted will be true reproductions of those acting upon the microphonic contact.

The greater the current, the greater will be the amplitude of the ripples and the louder the sounds given out by the telephone. But, except for a short time, a single point contact can only carry a very minute current without overheating and other troubles setting in, and hence the only way of providing enough current to give ripples of sufficient magnitude for an extensive telephone system is to employ a large number of contacts in parallel. In order to add to the number of contacts in parallel without changing the conditions of the circuit, however, it would be necessary at the same time to increase the number of contacts in series, so as to avoid any change in the resistance of the circuit. This consideration suggests that to double the current in the microphone four times the number of granules of carbon would be necessary. This is, in rough outline, the principle underlying the multiple contacts of Hughes and embodied in the modern granular microphone. Mr. Cohen's recent paper* states that the number of granules of carbon in the type of transmitter used in the British telephone service is rather greater than 100 000, and with this large number the microphone actually transmits, in the form of current ripples, between 100 and 200 times as much power as it receives in the form of sound waves.

* B. S. Cohen: "Apparatus Standards of Telephonic Transmission, and the Technique of Testing Microphones and Receivers," *Journal I.E.E.*, 1928, vol. 66, p. 171.

The microphone in common use is therefore vastly more powerful than a Bell telephone would be if it were used as a transmitter, as it was in the early days. The Bell telephone takes the first place, of course, because it does the speaking. It is, however, the immense power of the microphone when used as a relay and transmitter that enables a telephone system to cover a wide area, the size of which has grown with the gradual improvement of the microphone, among other things.

We began by speaking to subscribers in the same town, then from town to town, and finally the telephone system extended over the whole area of a country no larger than ours. At this stage there came a pause, further extension being difficult if not impossible. Then the thermionic-valve relay, which we owe to Sir Ambrose Fleming and Dr. de Forest, was introduced. The valve being a perfect relay, almost unlimited progress now seems possible, and within a few years we have seen the power of speech extended over the whole world. This amazing extension of area has rather tended to concentrate attention upon the wireless paraphernalia of transmission —the valves, the aerials, the electromagnetic waves which are propagated in the ether, and the Heaviside layer, which keeps everything within bounds. Let us remember, however, that, wonderful as all these are, they are accessories incidental to the main purpose. Not one of them is capable, in itself, of hearing or speaking a single word. It is the microphone that listens to us, and the telephone that speaks to us. Friendly speech brings men together as nothing else can, and Graham Bell and David Hughes, who gave us the telephone and the microphone, deserve to be honoured every day of our lives. It would be too much to suggest that you should think of these two benefactors of mankind whenever you use the telephone, but the next time you are rung up by some far-distant friend, and hear his well-known voice speaking to you when you lift the telephone to your ear—give a passing thought to Graham Bell. And then, when you speak into the mouthpiece of the transmitter—knowing that the microphone inside it will respond and that the current ripples which faithfully represent your voice will be carried far away to your friend—remember what you owe to David Hughes.